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Articulated Lean Compensated Motorcycle headlight

Summer Project

Tarun Singh and Rohith Rudraswamy Sali
UNIVERSITY OF COLORADO BOULDER

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Objective

To design a self-adjusting headlight for motorcycle to increase visibility around curves and over hills.

Literature survey

- BMW K 1600 GT is installed with adaptive headlights which uses mirrors for steering light along the direction of the curve based on the speed and yaw angle of the bike.

Fig 1: Headlight on BMW K 1600 GT

- JW Speaker-Adaptive LED Headlights – Model 8790 Adaptive headlights use selective illumination of different set of LED lights depending on the yaw angle of the bike.

Fig 2: JW speaker

INTRODUCTION:

You're driving home from a weekend vacation. It's late at night, and the winding two-lane road has no streetlights. You approach a curve at 40 mph -- slow enough to make the turn, but too fast to stop suddenly if you need to. What's waiting there, just beyond the range of your headlights? A stalled car? A deer?

With adaptive headlights, there's no guessing game. The lights turn their beams around each bend in the road, giving you a better view of what's ahead. Improved night driving isn't a trivial matter -- over 46 percent[2] of fatal accidents occur at night, a number much higher than the proportion of driving done at night. We'll look at how adaptive headlights differ from standard headlights and find out how they can make nighttime driving safer.

Standard headlights shine straight ahead, no matter what direction the motorcycle is moving. When going around curves, they illuminate the side of the road more than the road itself. Adaptive headlights react to the steering, speed and elevation of the bike and automatically adjust to illuminate the road ahead. When the bike turns right, the headlights angle to the right. Turn the bike left, the headlights angle to the left.

The headlight is pitch compensated to maintain the elevation of the beam while making turns. The degree of upward movement of headlight depends on the bank (roll) angle of the bike.

This is important not only for the rider of the bike with adaptive headlights, but for other drivers on the road as well. The glare of oncoming headlights can cause serious visibility problems. Since adaptive headlights are directed at the road, the incidence of glare is reduced.

A bike with adaptive headlights uses electronic sensors to detect the speed of the bike, how far the rider has tilted the bike to turn. Roll is the rotation of the bike around the vertical axis. The sensors detect this change in ROLL and direct small electric motors built into the headlight casing to turn the headlights.

The design that we used is cost effective compared to JW Speakers and BMW and it is simple to implement which requires two motors and ultrasonic sensors. The JW Speakers does not use the full intensity of lights at curves and use only the additional light source to illuminate the curves which is not very efficient. The adaptive headlights implemented by BMW on the other hand uses reflective mirrors to direct light beam in the desired direction. Once again not the full intensity of the light beam is utilized, only a part of it is reflected by mirrors.

The headlights from BMW have access to all the sensors from the ECU of the bike, JW Speakers don't have this luxury, they have onboard sensors (which sensors? This information is conveniently missing from their website) to measure the lean angle.

Fig 3: Comparison between conventional and adaptive headlights

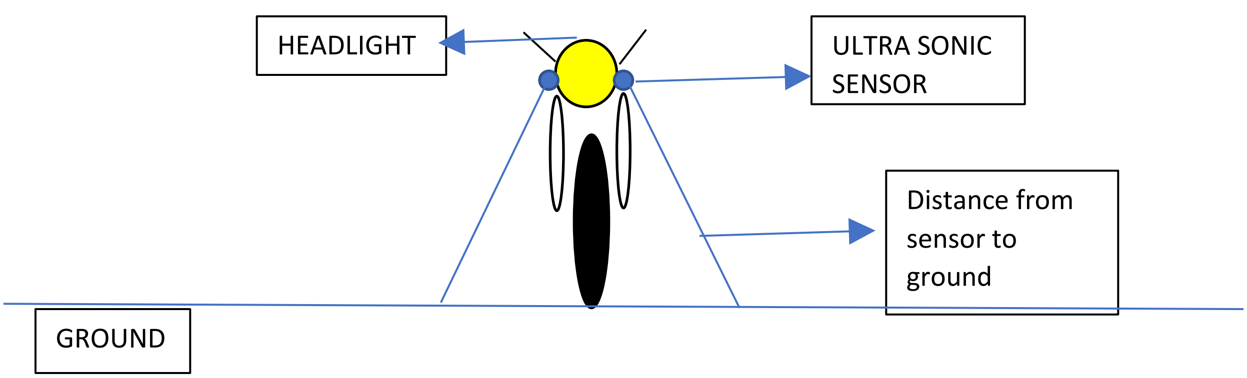

Fig 4: Distance read by both ultrasonic sensors is same when the bike is upright

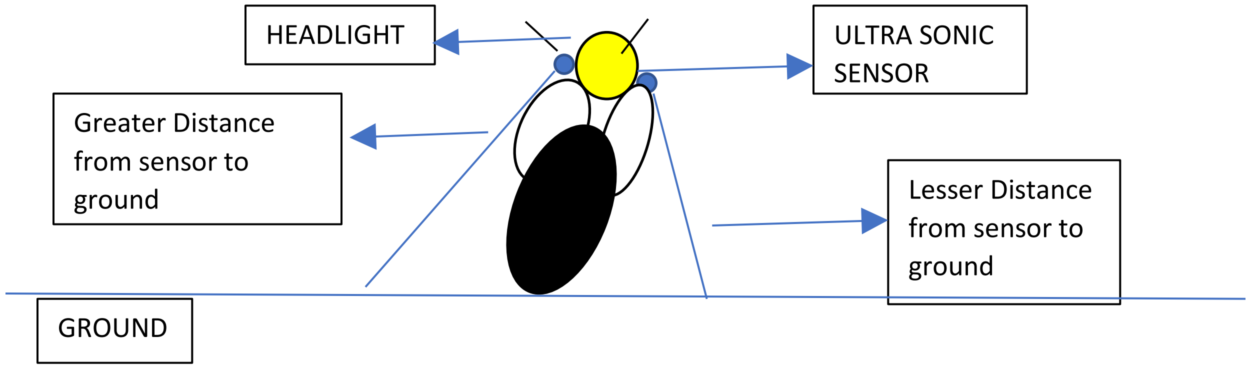

Fig 5: Distance read by both ultrasonic sensors is different when the bike is tilted

Block Diagram:

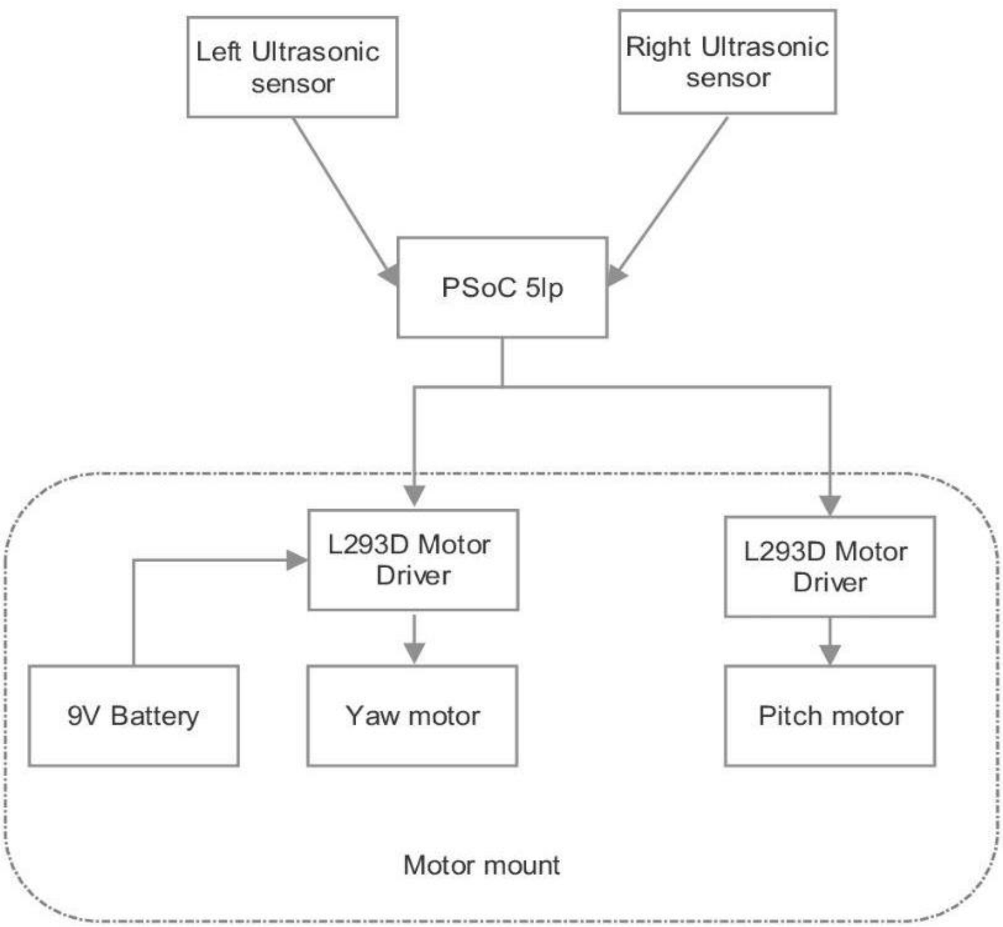

Fig 6: Block Diagram

COMPONENTS USED:

a) PSOC 5lp CY8C5888LTI-LP097:

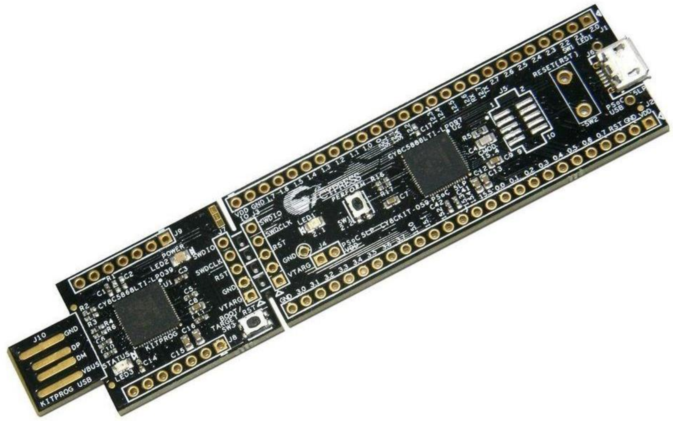

Fig 7: Board used PSOC 5lp CY8C5888LTI-LP097

32-bit ARM-Cortex M3 processor with 64kb of SRAM and 256kb of flash memory.

b) HRLV EZ4

Fig 8: Ultrasonic sensor used: HRLV EZ4

The HRLV-MaxSonar-EZ sensor line provides high accuracy and high resolution ultrasonic proximity detection and ranging in air. This sensor line features 1-mm resolution, target-size and operating-voltage compensation for improved accuracy, superior rejection of outside noise sources, internal speed of-sound temperature compensation and optional external speed-of-sound temperature compensation. This ultrasonic sensor detects objects from 1-mm to 5-meters, senses range to objects from 30-cm to 5-meters, with large objects closer than 30-cm are typically reported as 30-cm. The interface output formats are pulse width, analog voltage, and serial digital in either RS232 or TTL.

The EZ4 differ from others with respect to beam width and resolution. It has the narrowest beam with in EZ series and a resolution of 1mm.

c) HC-SR04

Fig 9: Ultrasonic sensor used initially HC-SR04

This is a low cost ultrasonic sensor initially used for testing. Due to its low noise reduction, accuracy and reliability HRLV max sonar EZ4 was used. The sensor is not designed to work above 15 degrees with respect to normal which was a major drawback and does not have inbuilt noise compensation circuit.

d) Stepper motors:

Yaw motor:

STP-42D201-37 - Shinano Kenshi

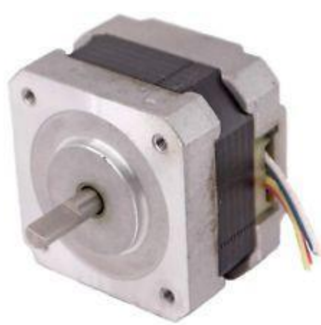

Fig 10: Yaw stepper motor

12 Volt 1.8 Step Angle Bipolar Stepper Motor with Holding torque of 3200 g-cm.

e) Pitch motor:

BYJ48 Stepper motor

Fig 11: Pitch stepper motor

12 Volt 1.8 Step Angle Unipolar Stepper Motor with Holding torque of 1200 g-cm.

f) L293D motor driver:

Fig 12: L293D Motor driver

The L293D drive DC motors or one bi-polar or uni-polar stepper with up to 600mA per channel.

g) SparkFun Snappable Protoboard:
https://www.sparkfun.com/products/13268

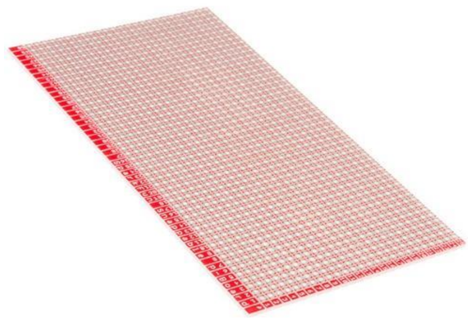

Fig 13: PCB proto board used to solder all parts together

Protoboard used to make the design compact with microprocessor and driver IC's

SCHEMATIC:

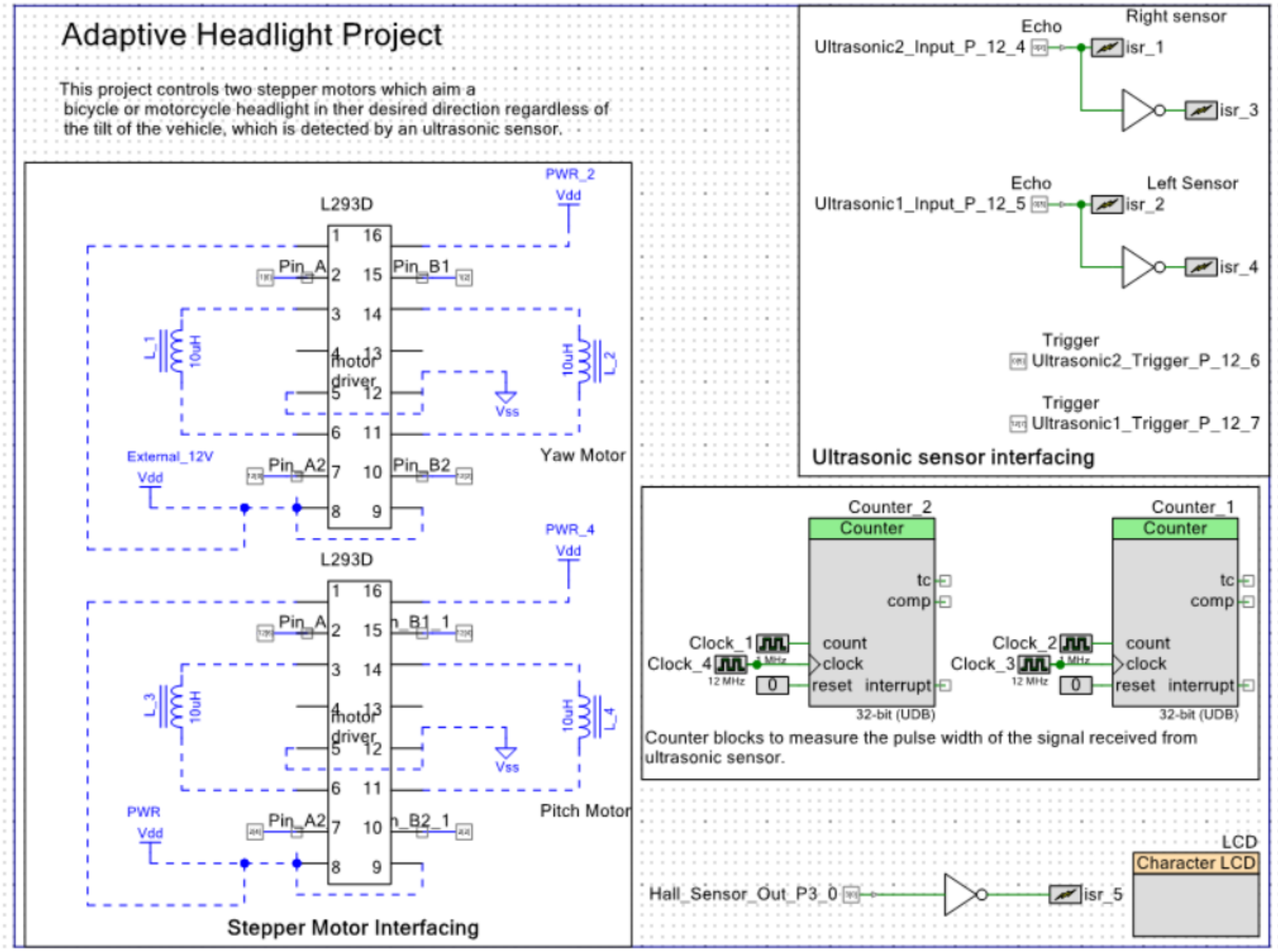

Fig 14: Project Schematic

MECHANICAL DESIGN:

The designs were designed using SolidWorks software. The 3D designs were 3D printed using PLA material.

a) Yaw motor Mount

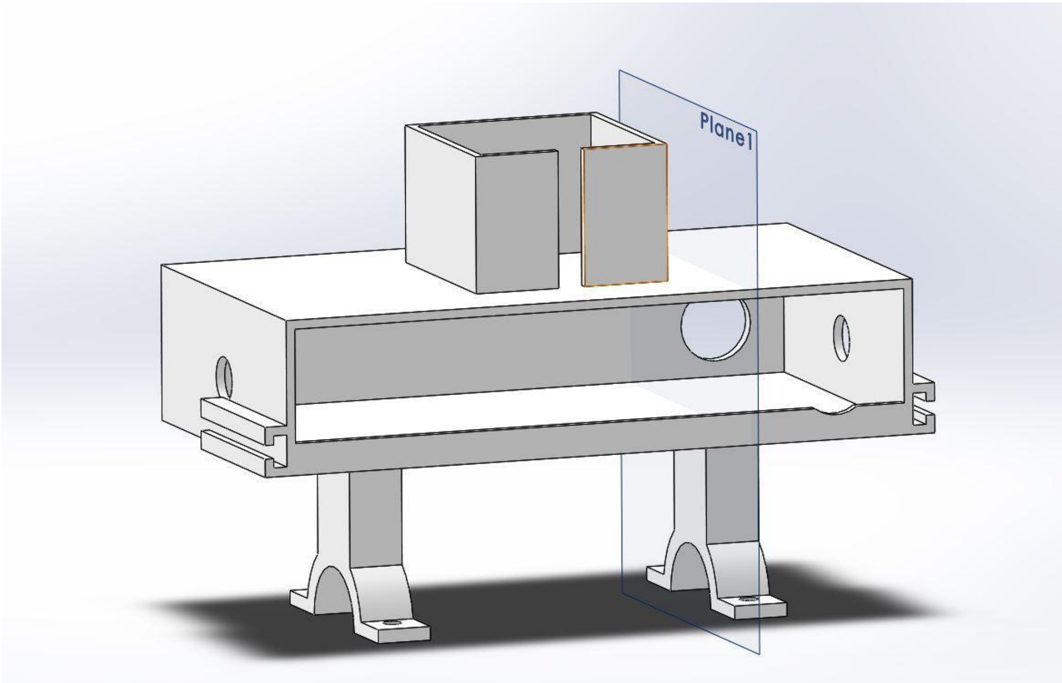

Fig 15: Yaw motor mount

b) Pitch motor Mount

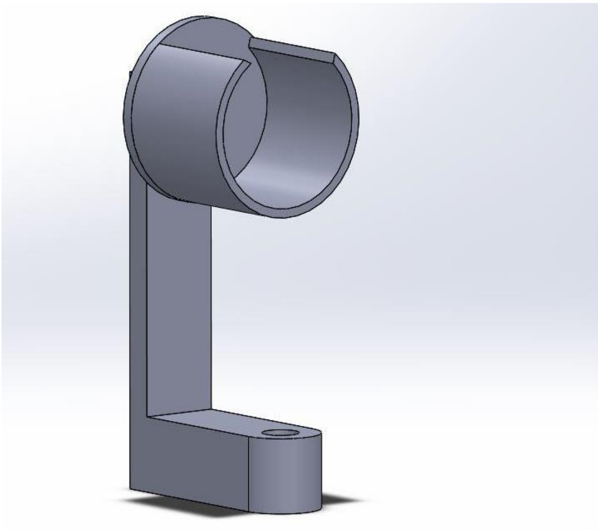

Fig 16: Pitch motor mount

c) Sensor mount

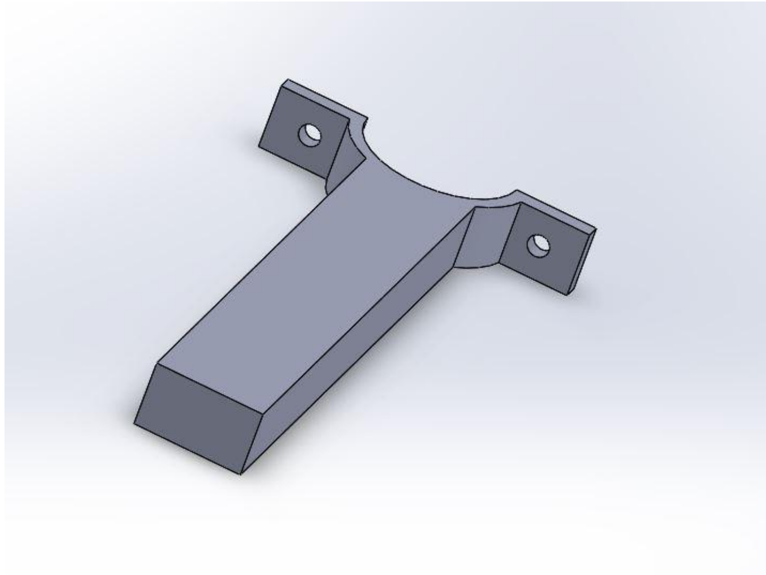

Fig 17: Ultrasonic sensor mount

d) Flashlight mount

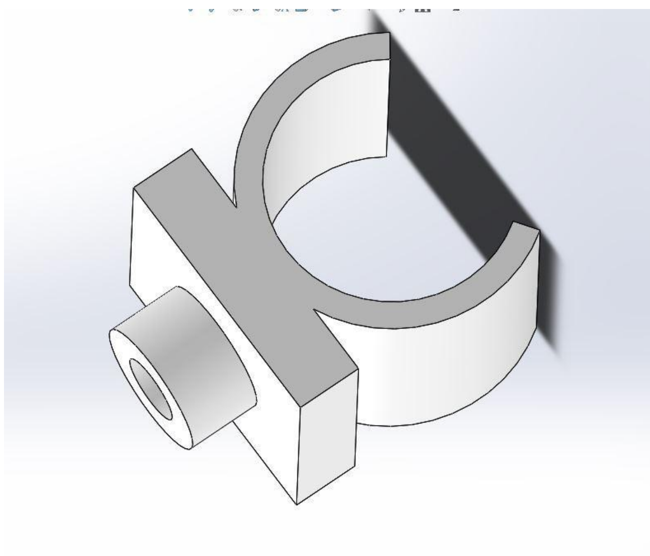

Fig 18: Flashlight mount

e) Mechanical constraints for home position

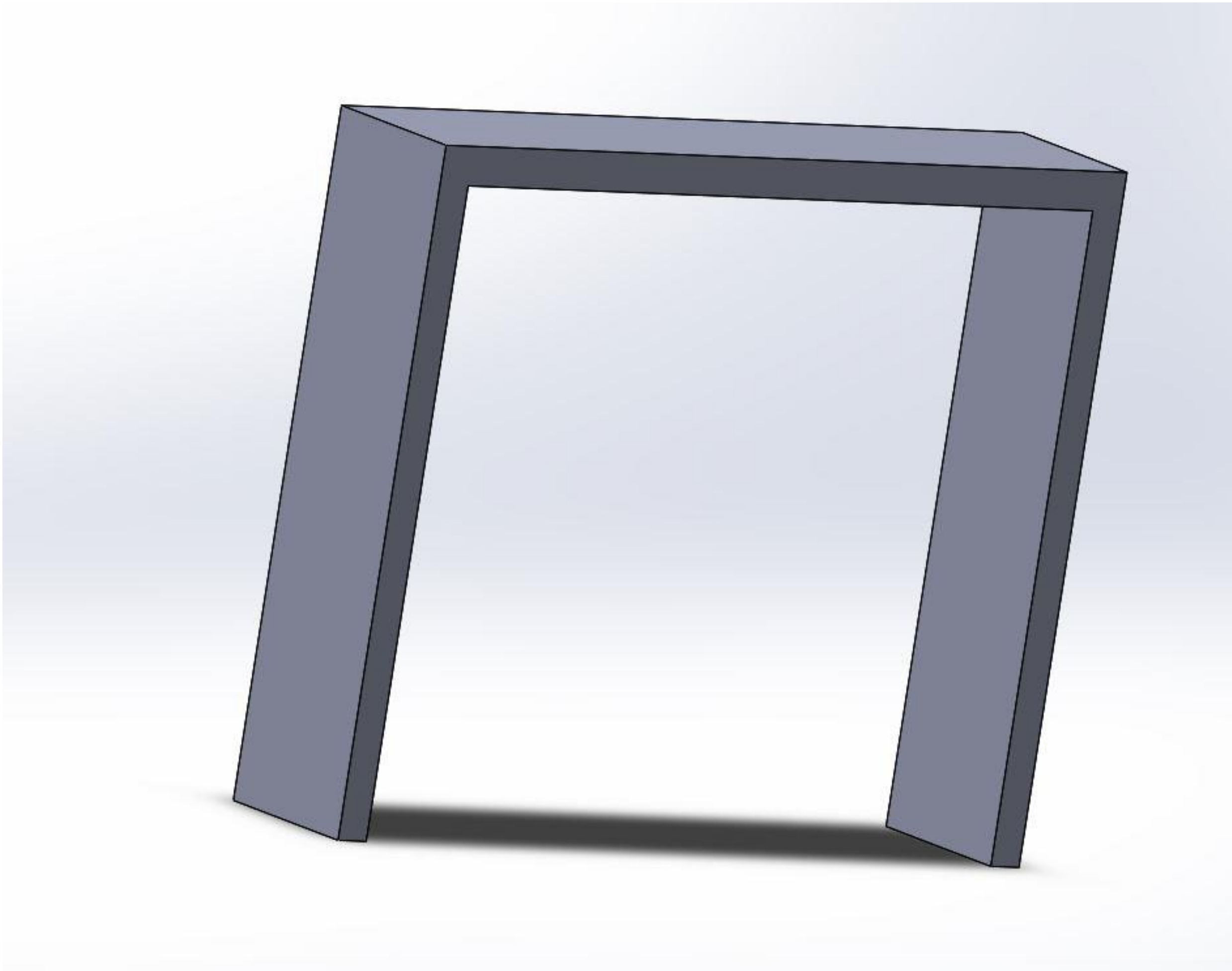

Fig 19: Mechanical constraints for home position reset

CODING LOGIC:

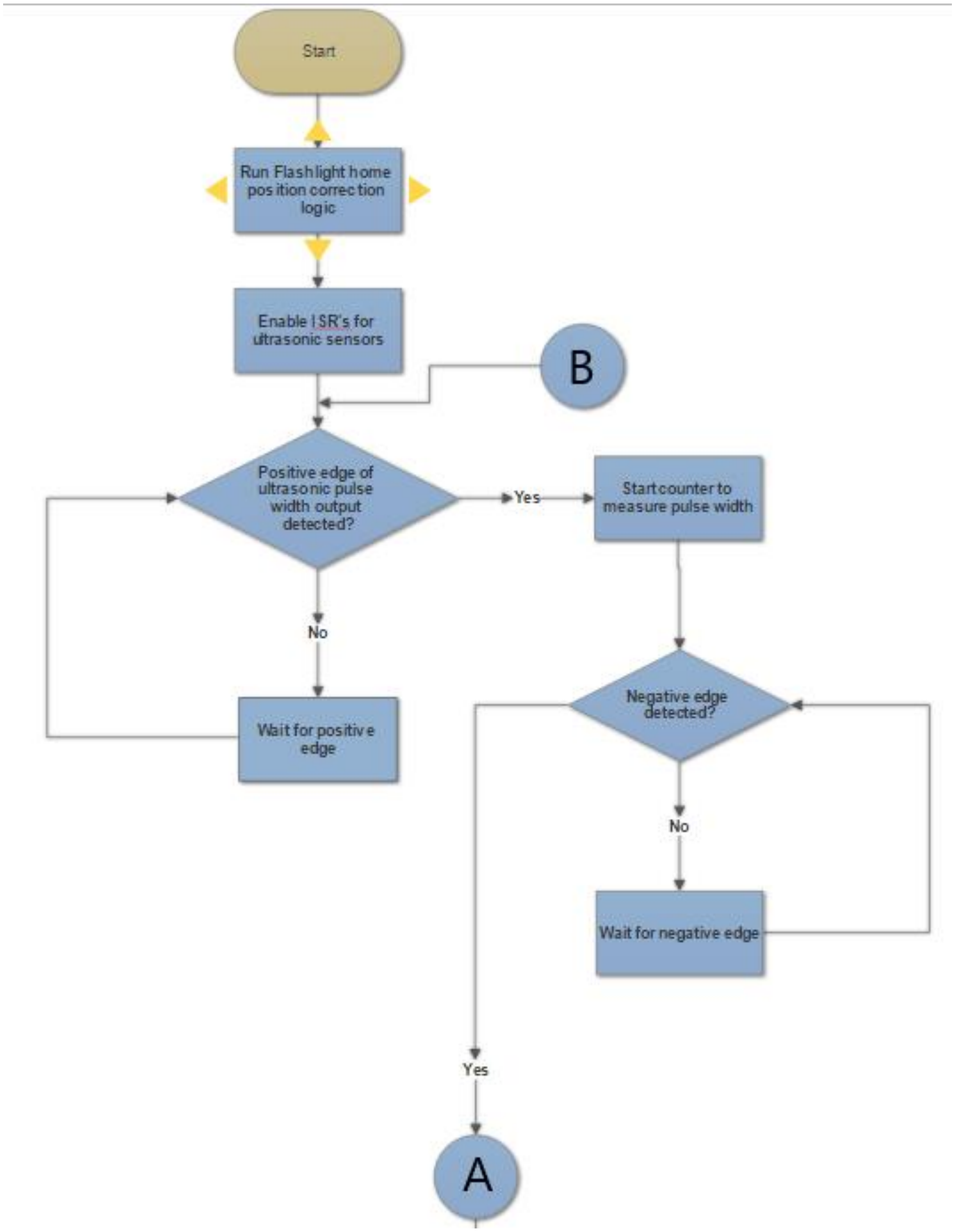

Fig 20 a): System Flow chart

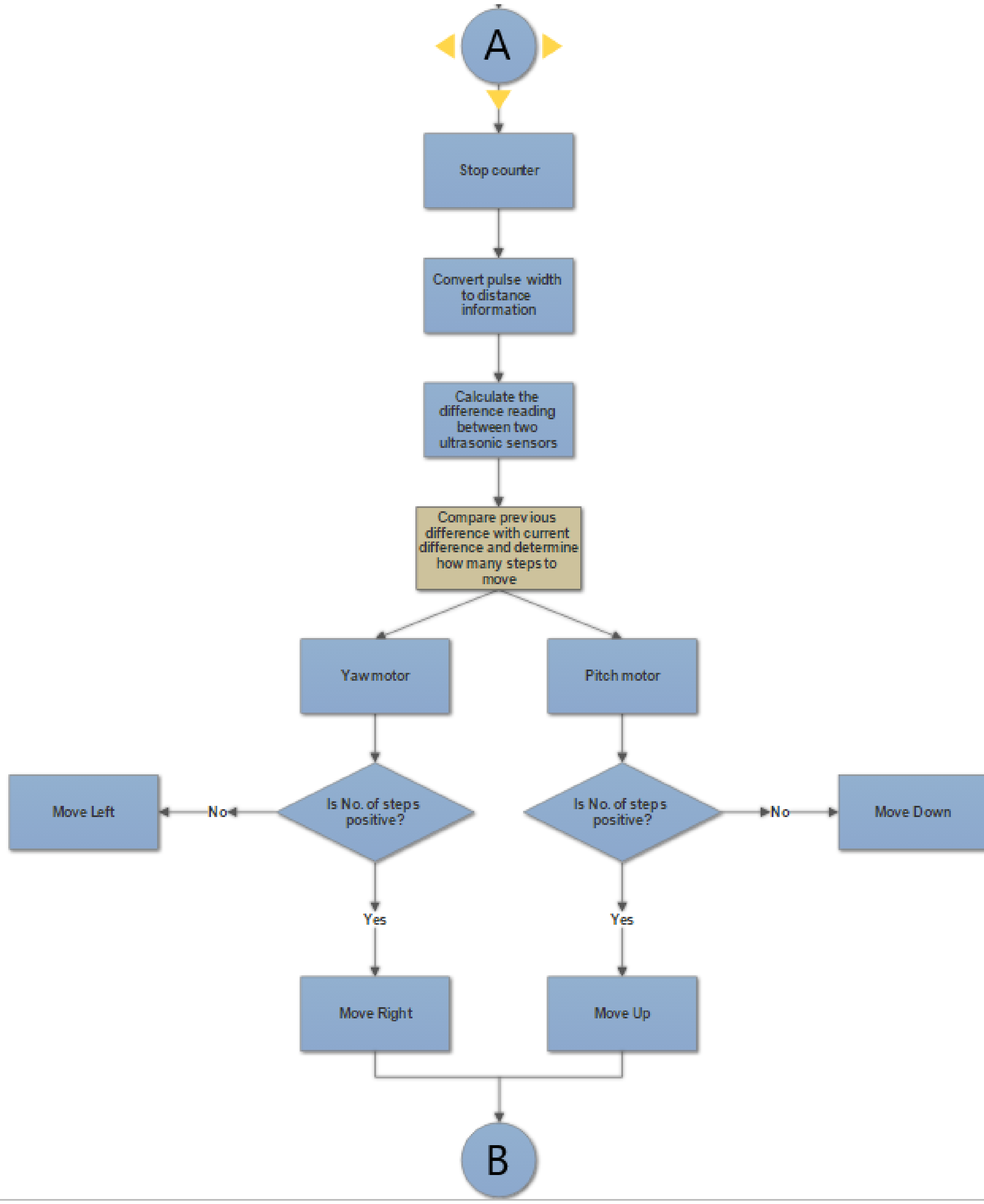

Fig 20 b): System Flow chart (continued..)

Schedule:

Month	Week	Work Done
June	1	Initial project proposal and literature survey. Reading related patents. Brainstorming ideas, sensor choice, design choice. (Gyroscope vs Accelerometer vs Ultrasonic sensors)
	2	Interfacing ultrasonic sensor (HC SR04). Integrating the second ultrasonic sensor. Had plenty of issues with ISRs. Had to slow down the frequency of triggering the sensors to have sufficient time to process the previously acquired data Testing the ultrasonic sensors on different surfaces and angles
	3	Designed a cardboard prototype with ultrasonic sensors and motor. Tested the prototype over different angles and surfaces.
	4	Ultrasonic sensors working over extended range of ~1m and improvement of precision with a new hardware design. Interfacing pitch motor. Took classes for 3d printing and laser cutting
July	1	Learning curve associated with solid works. Mechanical design
	2	3d printing parts. Hall sensor interfacing for home position detection
	3	Testing the sensors for extended angles, beyond 15 degrees, lost the signal at this tilt with HC SR04. Tried improving SNR using averaging, median filtering
	4	Interfacing wide beam ultrasonic sensor HRLV EZ4. Integration with previous code
August	1	Mechanical design change, had to move sensors closer to the ground, parallel to it. Implemented look up table for both pitch and yaw motor to include multiple steps based on tilt.

	2	Compacting mechanical design, cleaning up connections by soldering parts onto protoboard and testing. Re print damaged parts Implemented half stepping instead of full stepping to reduce the jerky movement of yaw motor
	3	Re design mechanical mount to restrict motor movements which helps in home position detection without hall sensor. Field testing. Trying micro stepping to implement smoother yaw motion
	4	Recording test data. Finalizing report

Table 1: Project schedule followed

PROBLEMS FACED:

a) **HCSR-04 ultrasonic sensor**

These sensors were not accurate and reliable. Faced problems with improving the accuracy and eliminating noise. It did not work well with tilt of the sensor above 10 degrees which was a major drawback.

Maxsonar HRLV-EZ4 ultrasonic sensor was used which was better in accuracy, eliminating noise, faster sampling and tilt compensation. It works well till 20 degrees of tilt.

According to the initial design, sensors were supposed to be placed closer to the handle bars. They were being hindered by the front tire and moving legs while pedaling the bike. Hence, we had to move the sensors closer to the ground, near the shock absorbers.

b) **Determining Home position of the motor**

Initially hall sensor was used to determine the home position. It worked well for yaw motor but not for pitch motor. Hence to determine the home position of yaw and pitch motor mechanical constraints were used.

Mechanical constraint method

The mechanical constraints restrict the motion of the motor to continue its rotation in one direction. The number of steps required from the constraints is determined. The motors are moved the required number of steps to achieve the home position.

c) **Problems with 3D printing:**

1. Parts were not being printed in accordance with the measurements specified/ Parts not fitting together (Needed to choose scaling and high detail option appropriately)
2. Parts having low density, and hence fragile. (There is an option to change the printing density, which we came to know later)
3. 3D printing being interrupted by other students. We came to know later that we need to get special permission to print parts taking more than 8 hours to print.

d) HRLV EZ4 ultrasonic sensor:

We faced issues with triggering this sensor. Manual triggering wasn't giving expected results, so we had to auto trigger the sensor.

Our initial design had the sensor pointed to the ground at an angle. Had to re-orient the sensor to point exactly perpendicular to the ground, so that we could achieve a higher bank angle.

e) Issues with integrating two ultrasonic sensors together:

The working principle behind the ultrasonic sensor is to measure the time that the ultrasonic beam takes to travel from the sensor to the target and back. This information is obtained as a PWM output from the sensor. The pulse width is directly proportional to the distance of the target.

To measure this pulse width, we used counters. The counter had to started exactly at the rising edge of the pulse and had to be stopped exactly at the falling edge of the pulse.
Timing was of utmost importance. Having the timing information of both sensors without errors was challenging in code.

f) **Yaw motor not getting enough torque to hold position:**
When we took our system for a spin along the Boulder creek path, we noticed that yaw motor was not able to hold its position when the path was bumpy. The yaw motor was not able to provide sufficient torque. The motor driver that we used L293D, has a max drive current specification of 700 mA. But our motor can take upto 1.7 A. The design clearly requires a driver which can support higher drive current.

g) **Detecting home position for both yaw and pitch motors:**
Our initial plan was to detect the home position using hall sensor. We implemented it for the yaw motor. But, we were unable to think of a way to implement it for the second motor as well, mechanically. (Where and how exactly to mount the second hall sensor?)
The idea is to
As a workaround, we came up with mechanical constraints to restrict motor movement in both yaw and pitch directions.

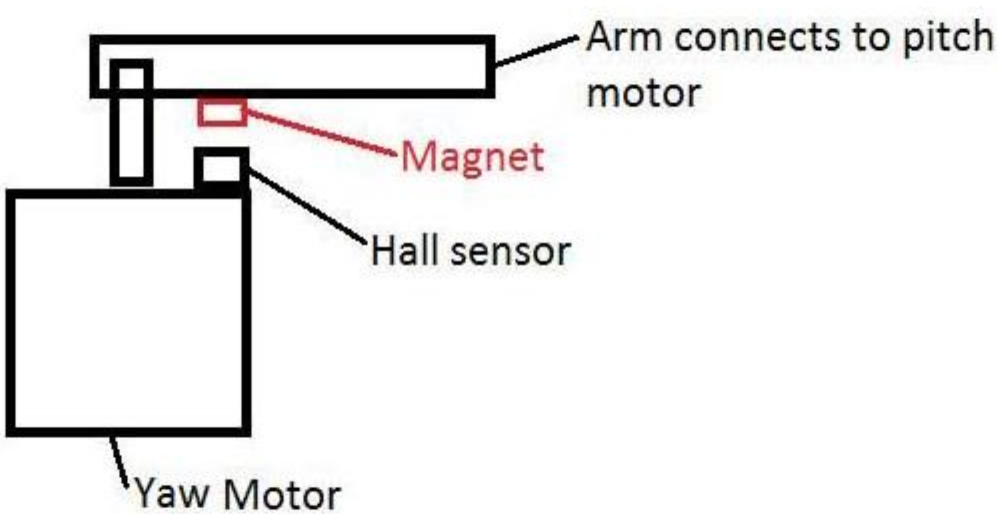

Fig 21: Hall sensor method for detecting home position

With hall sensor method, the motor makes a searching sweep, the moving arm is glued with a piece of magnet, the hall sensor is fixed on the mount. As the motor makes the sweep, if the magnet passes over the hall sensor we get a negative edge which can easily detected and processed in software.

h) Issues with AutoCAD:

Initially we tried to make the mechanical designs using AutoCAD, but it had intricate user interface and options. As a workaround, we opted for Solid Works.

i) Hall sensor:

The hall sensor that we used detects a particular pole of the magnet. The orientation of the magnet matters. Please note that this applies to the initial method of home position detection. We ended up using mechanical constraints to detect home position.

j) Full stepping vs Half stepping:

Full stepping of the stepper motor was providing jerky movement. Smoother movement was achieved by switching to half stepping.

k) Micro stepping:

We are currently working on it to achieve even smoother movement of the yaw motor.

l) Reduced sample rate:

We had to reduce the sampling rate of acquiring data from ultrasonic sensors to around 10 Hz to filter out noise introduced due to over sampling.

Earlier we were shooting a trigger beam every 38 ms (max time required for beam to return and still be detected, according to the datasheet). This is way too quick than necessary, the frequent change in the distance readings resulted in unnecessary motor movement.

Setup Pictures:

Fig 22: Setup front view

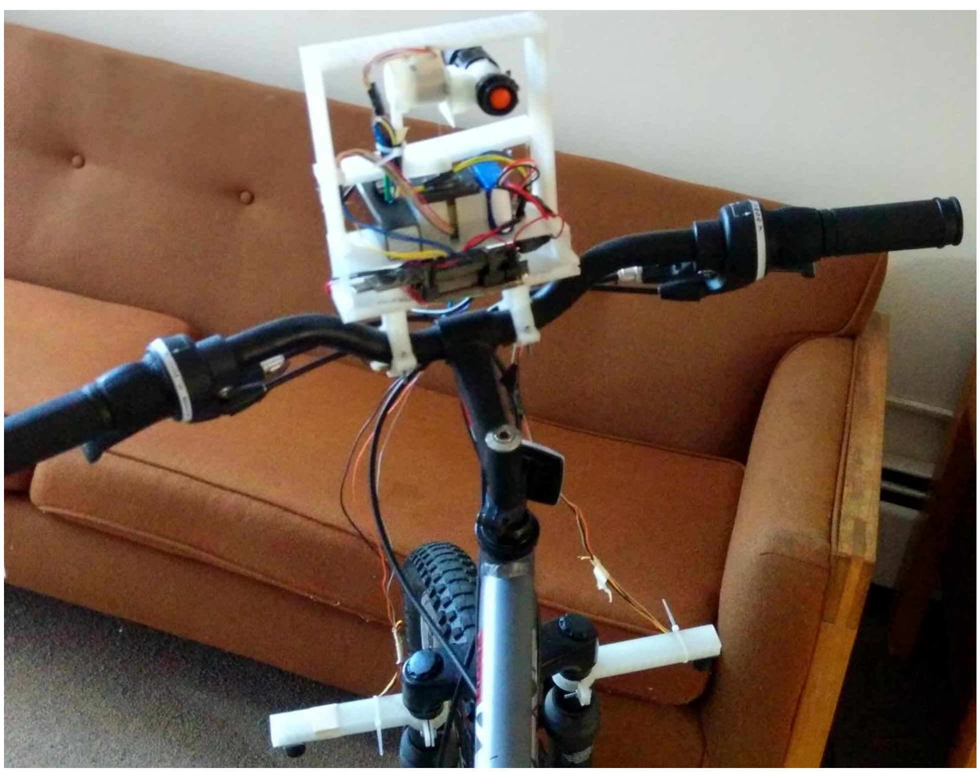

Fig 23: Setup rear view

RESULTS:

Repeatability of light beam when bike tilted left and right

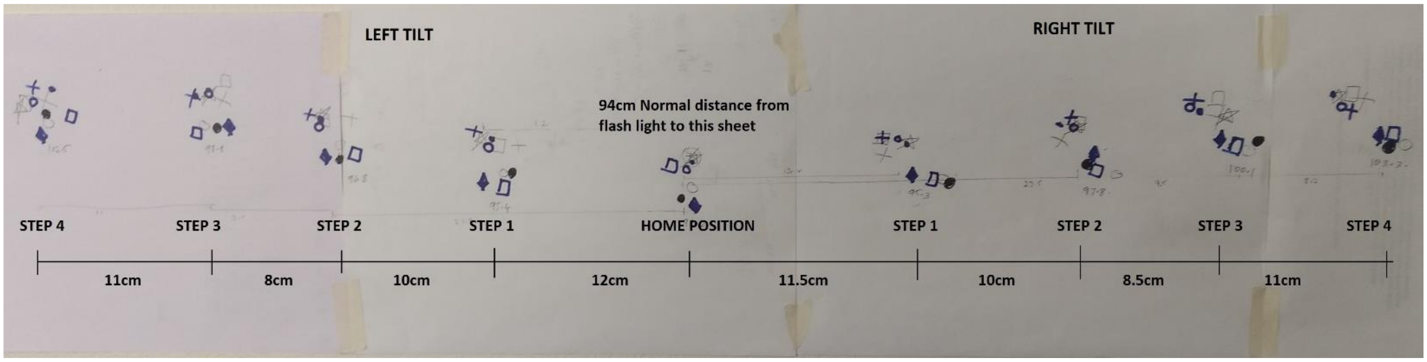

Fig 24: Plot of flashlight position with steps in both directions

We can see that the beam plots are grouped as clusters, instead of ideal points repeated over time. One possible explanation can be due to the half stepping that we have used to move the yaw motor. Half stepping is known to be less accurate than full stepping. Another explanation is unavoidable human errors while plotting these points.

Test data when bike tilted left and right

Left Tilt				Right Tilt			
Step 1	Step 2	Step 3	Step 4	Step 1	Step 2	Step 3	Step 4
10°	12°	14°	20°	10°	13°	15°	21°
10°	14°	16°	21°	10°	13°	15°	22°
10°	15°	16°	18°	9°	13°	16°	23°
8°	11°	13°	20°	10°	12°	14°	20°
9°	10°	12°	18°	10°	12°	15°	21°
10°	12°	14°	19°	11°	13°	15°	21°
9°	13°	16°	25°	10°	12°	14°	20°
10°	15°	17°	23°	10°	12°	14°	20°
10°	12°	14°	20°	9°	11°	14°	20°
10°	11°	15°	18°	9°	12°	15°	22°

Table 2: Tilt angle vs stepper motor steps

Plot of bank (roll) angle vs number of steps of stepper motor when the bike tilted towards left

Method Followed: Bike was titled left from home position till the first correction step was noticed. At this point, the lean angle was measured. Continue the same procedure for second, third and fourth steps.

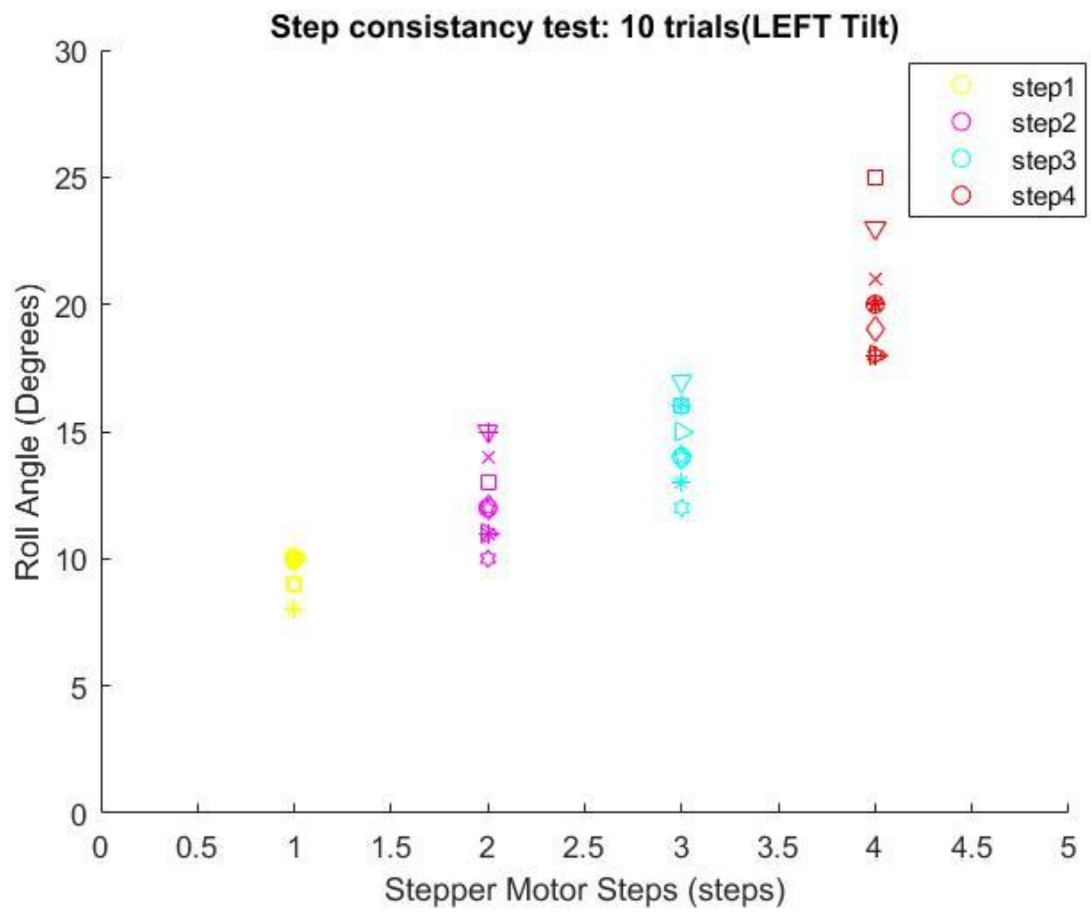

Fig 25: Graphical plot of Roll angle vs stepper motor steps (LEFT tilt)

Plot of bank (roll) angle vs number of steps of stepper motor when the bike tilted towards right

Method Followed: Bike was titled right from home position till the first correction step was noticed. At this point, the lean angle was measured. Continue the same procedure for second, third and fourth steps.

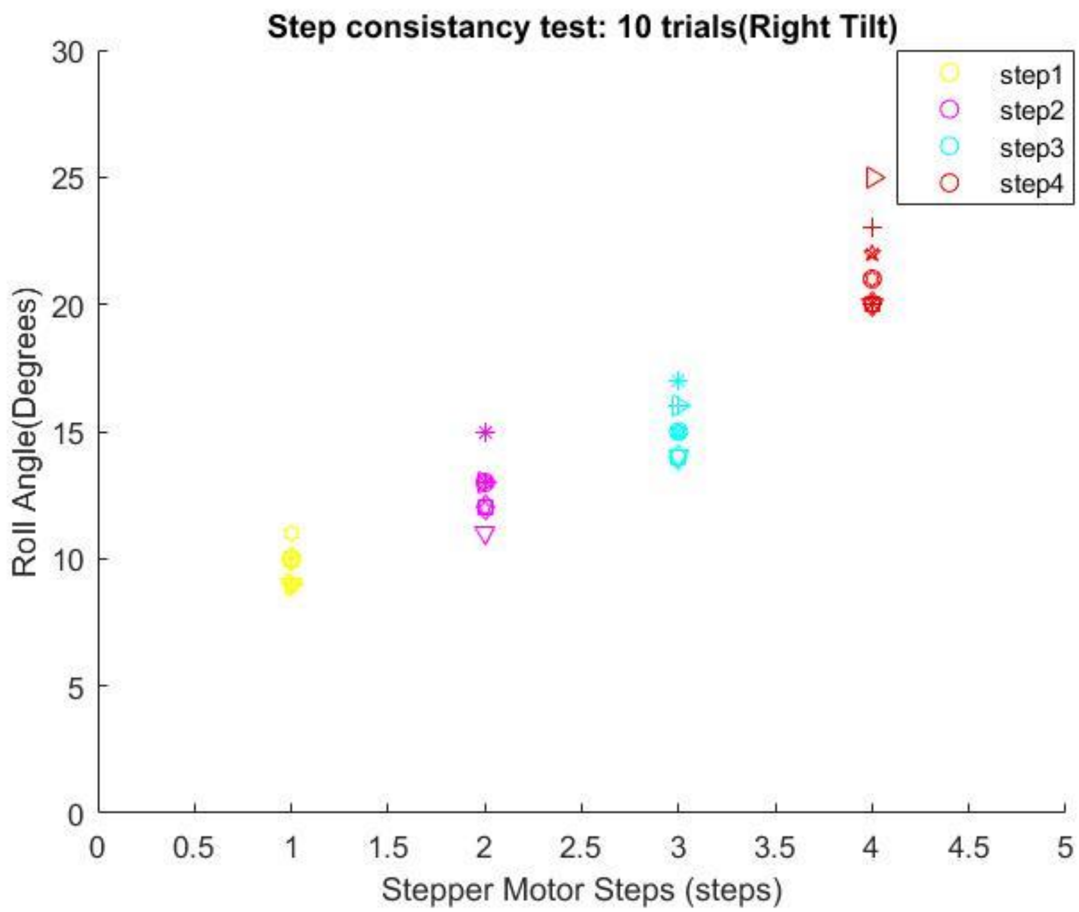

Fig 26: Graphical plot of Roll angle vs stepper motor steps (Right tilt)

Future Scope

1. Compensate for the speed of the motorcycle using hall sensors. The motors speed in adapting to the curves is determined by the speed of the bike.
2. Using series of ultrasonic sensors on each side to obtain bank angle of the bike more than 20 degrees.
3. Smoother motion of the headlights using micro stepping.

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